5

OPERATIONAL AMPLIFIER AND ITS APPLICATIONS

Operational Amplifier (Op-Amp) is a very high-gain directly coupled negative - feedback multistage amplifier. It is a circuit that can perform mathematical operations such as addition, subtraction, integration and differentiation. The main electronic circuit in an Op-Amp is the differential amplifier.

Differential amplifier

It is a basic unit of op-amp. It is having differential input. It amplifies the difference of two input signals. If v_1 and v_2 are two input signal, the output voltage of this amplifier is

$$v_0 = A(v_1 - v_1)$$

where A is the gain of Op-Amp.

Problem

1. *The open - circuit voltage gain of a differential amplifier is 50. The two input signals are* $v_1 = 5.21\text{V}$ *and* 5.11V. *Find output voltage.*

$$v_0 = A(v_1 - v_2)$$

$$= 50(5.21 - 5.11) = 50 \times 0.10 = 5\text{V}$$

Circuit of Differential amplifier

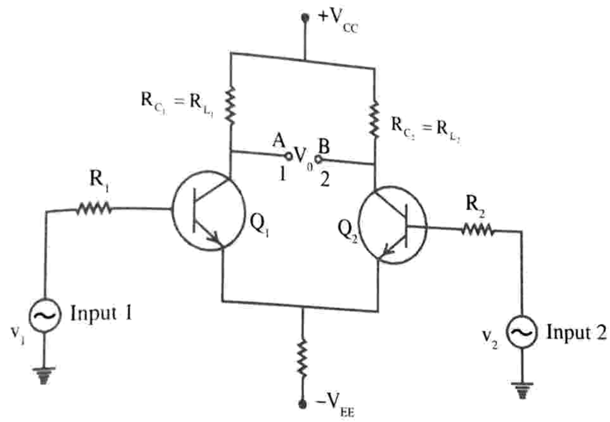


Fig. 5.1

Fig. 5.1 represents the schematic diagram of the differential amplifier. Q_1 and Q_2 are two identical transistors. Their characteristics are the same. The collector resistors R_{C_1} and R_{C_2} are equal. They are connected to $+V_{CC}$. The emitter resistance R_E is common to both the transistors. its other end is connected to $-V_{EE}$. The two inputs v_1 and v_2 are equal. They are connected to the bases of Q_1 and Q_2. Output is taken between two collectors. In total, there is a symmetrical arrangement on either side.

When a signal is applied to only one base and the other base is grounded, the input is single ended. Now only input v_1 is ON and v_2 is OFF. Transistor Q_1 acts like a CE amplifier. Now an amplified and inverted voltage v_{0_1} appears at its collector.

R_E is connected in common for both emitters so that both emitter voltage $= \frac{1}{2} v_1$ exists at common emitter point. This voltage results from emitter follower action of transitor Q_1. Voltage gain of emitter followers is lesser than unity. So same voltage appears at the emitter of Q_2. The voltage between base and emitter has a phase reversal of 180° with input voltage v_1. Hence a single input voltage v_1 develops the output voltages of same magnitude at both collectors with opposite polarities. This is due to the fact that base to emitter voltages have the same magnitude for both Q_1 and Q_2.

Similar explanation holds good for the base (input) of Q_2 is applied with v_2 and the base of Q_1 is grounded.

The contribution of the first source acting alone $v_{0_1} = Av_1$

The contribution of the second source acting alone $v_{0_2} = -Av_2$

When both sources act simultaneously, resultant output voltage,

$$v_0 = v_{0_1} + v_{0_2}$$
$$= Av_1 + (-Av_2)$$
$$v_0 = A(v_1 - v_2)$$

Problems

2. *What is the advantage of a differential amplifier over an ordinary CE amplifier?*

   Ans: Differential amplifier attenuates the common mode signal.

Operational Amplifiers (Op-Amp)

3. *What is an Op-Amp?* *(CU Nov. 2016)*

   Ans: It is a very high-gain, directly coupled negative-feedback multistage amplifier. It is a circuit that can perform mathematical operations such as addition, subtraction, integration and differentiation.

4. *State the characteristics of an ideal Op-Amp* *(CU Nov. 2016)*

   Ans: 1. Infinite voltage gain.

   2. Infinite bandwidth (Voltage gain remains constant over a wide frequency range)

   3. Infinite input impedance (None of the input terminals draw any current)

   4. Zero output impedance ($< 200\Omega$) (Any amount of current can be drawn without disturbing input voltages. So it can provide constant output voltage).

   5. Perfectly balance circuit.

   6. Perfectly stable circuit. i.e., no effect of temperature/voltage variation on its parameters.

   7. Very large CMRR (> 90 dB)

Block diagram of Op-Amp

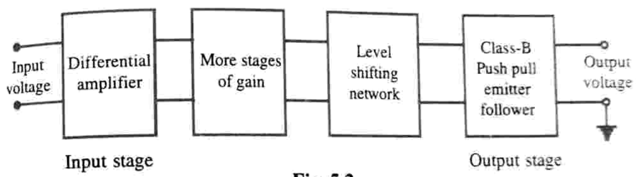


Fig. 5.2

The internal stages are direct coupled. i.e., no coupling capacitors are used. ∴ It can amplify both dc as well as ac signals. Two inputs are there – **inverting and non inverting**. It has very large Common Mode Rejection Ratio CMRR (> 90 dB)

Schematic symbol of Op-Amp

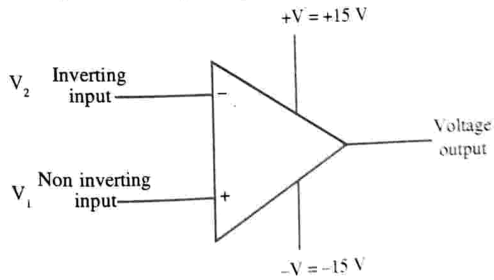


Fig. 5.3

$-ve$ indicates inverting input

$+ve$ indicates noninverting input

The signal applied to +ve terminal will appear in the same phase at the output (Non inverting)

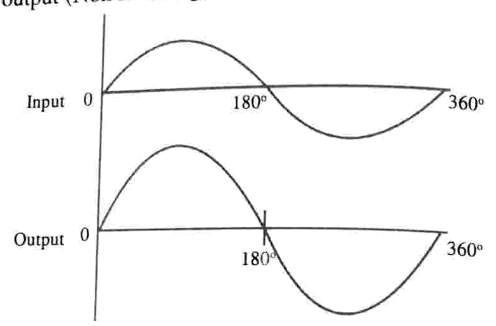


Fig. 5.4

But a signal applied to –ve terminal will be shifted in phase 180° at the output (Inverting)

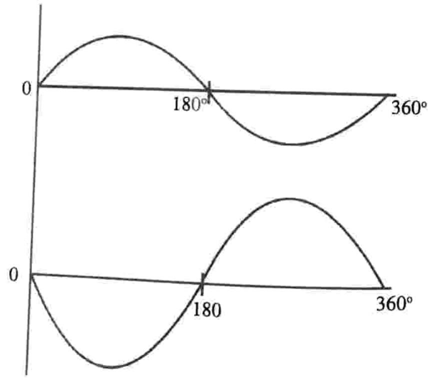


Fig. 5.5

V_1, V_2 and output voltage are measured with respect to ground. They are node voltages.

The differential input $V_{in} = V_1 - V_2$

If only one input is required, the other input is to be connected to ground.

IC 741 is an Op-Amp.

Problems

5. *What do you understand by the inverting and noninverting terminals of an Op-Amp?* *(CU Nov. 2016)*

6. *On what factors the output voltage from an Op-Amp for a given pair of input voltage depend?*

   Ans: i) Voltage gain of Op-Amp

   ii) The relationship between V_1 and V_2 i.e. $V_1 - V_2$ or $V_2 - V_1$

   iii) The supply voltages +V and –V

7. *Explain open loop voltage gain of an Op-Amp (A_{OL})*

   Ans: Maximum possible voltage gain from an Op-Amp is called A_{OL}.

   $A_{OL} > 10{,}000$.

Note: Open loop means there is no feedback from output to input.

8. *Explain closed loop voltage gain (A_{CL}) of an Op-Amp.*

   Ans: Generally Op-Amp is operated with negative feedback. i.e., A part of the output signal is fedback in phase opposition to input.

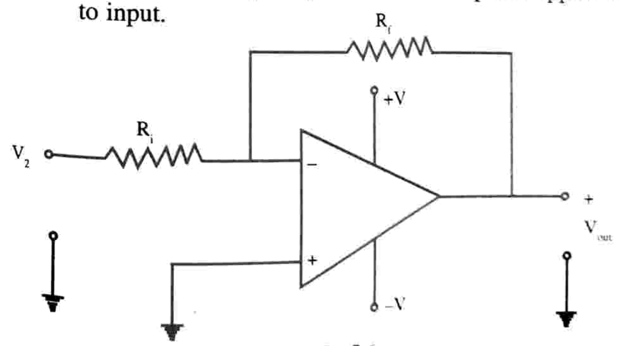


Fig. 5.6

In fig. R_i is the input resistance. R_f is the feedback resistor. Due to –ve feedback the voltage gain of the Op-Amp is reduced. The above circuit with feedback R_f is called closed loop and the voltage gain is called closed loop voltage gain (A_{CL}).

9. *What is the maximum voltage gain of an Op-Amp?*

Ans: A_{OL}. $\quad A_{OL} > 10{,}000$

10. *Why A_{CL} is lesser the A_{OL}?*

Ans: Due to negative feedback.

11. *What is the differential input voltage of Op-Amp?*

Ans: Differential input voltage (V_{in}) is the difference between the non-inverting input (V_1) and inverting input (V_2).

$$V_{in} = V_1 - V_2$$

12. *Explain the input output polarity relationship of Op-Amp.*

Ans: $$V_{in} = V_1 - V_2$$

When V_{in} is +ve the Op-Amp output voltage is +ve.

When V_{in} is –ve the output voltage is –ve.

For e.g.

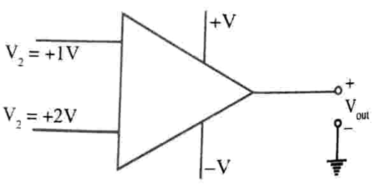


Fig. 5.7

$V_1 = +2V,\ V_2 = +1V$

$V_{in} = (+2) - (+1) = +1V$

$\therefore\ V_{out}$ is +ve

13. *Why dual power supply is used in Op-Amp?*

Ans: Normally supply voltages +V and –V are equal in magnitude. But they are opposite in sign.

e.g., ±15V, ±12V etc.

This allows the output voltage to swing both positive (> 0) and negative (< 0). We usually have two separate supplies; a +ve supply and an equal but opposite, negative supply. The common connection to these two supplies (i.e., the OV supply connection) acts as a common rail in the circuit. The input & output voltages are measured relative to this rail).

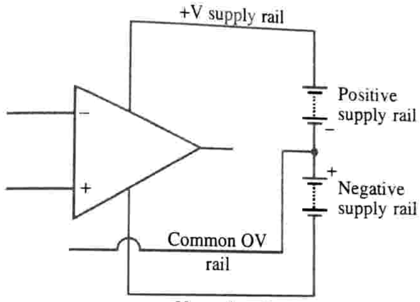


Fig. 5.8

Basic operation of Op-Amplifier

Most of the Op-Amps use negative feedback when they are used as amplifiers. For this the output terminal is connected to the input terminal through a resistor (R_f) which functions as feedback network.

If the input signal is connected to the –ve inverting input, through a resistor R_i and if the +ve noninverting terminal is grounded, then it is called inverting amplifier.

If the input signal is connected to the +ve non-inverting terminal and inverting (–ve) terminal is grounded through a resistor, it is called non-inverting amplifier.

When two inputs are connected to the two terminals respectively and difference between them is amplified, the arrangement is called Difference amplifier. Here the feedback arrangement controlls the amplification.

Inverting Amplifier

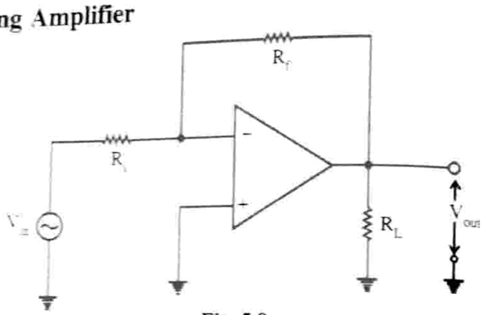


Fig. 5.9

R_i is the input resistance. V_{in} is connected to the inverting terminal. Output is fedback to input inverting terminal through a feedback resistor R_f. R_f provides –ve feedback. The +ve non-inverting input is grounded. Due to –ve feedback, output will be inverted (i.e., 180° out of phase).

We know op-amp has infinite input impedance (i.e. $Z_i = \infty$). So none of the input terminals draw any current. i.e., zero current at the inverting input.

$\therefore$ No voltage drop between inverting and noninverting inputs. This means that voltage at the inverting input is zero. Because the other input (+) is grounded. OV at the inverting input is called **virtual ground.**

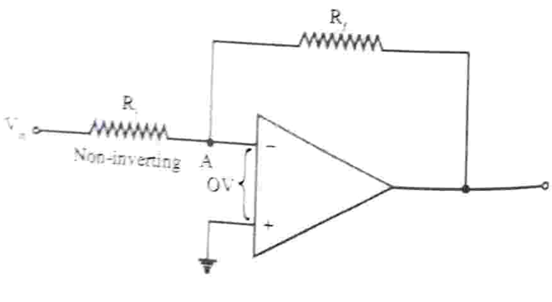


Fig. 5.10

In Fig. point A is at virtual ground. Because it is at OV. But is not physically connected to ground. So, it is called virtual ground.

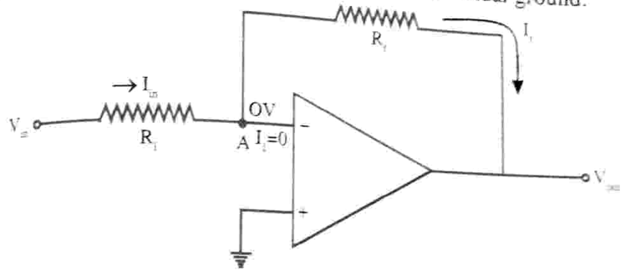


Fig. 5.11

$$I_f = I_{in} \qquad (\because \quad I_i = 0)$$

$$I_{in} = \frac{\text{Voltage across } R_i}{R_i} = \frac{V_{in} - V_A}{R_i}$$

$$= \frac{V_{in} - 0}{R_i} = \frac{V_{in}}{R_i} \qquad \dots (1)$$

$$I_f = \frac{\text{Voltage across } R_f}{R_f}$$

$$= \frac{V_A - V_{out}}{R_f} = \frac{0 - V_{out}}{R_f} = -\frac{V_{out}}{R_f} \qquad \dots (2)$$

$$I_f = I_{in}$$

$$\therefore \qquad -\frac{V_{out}}{R_f} = \frac{V_{in}}{R_i}$$

$\therefore$ closed loop voltage gain

$$A_{CL} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i}$$

$$A_{CL} = -\frac{\mathbf{R_f}}{\mathbf{R_i}}$$

–ve sign shows that output signal is inverted with respect to input.

Note: For inverting amplifier

1. $A_{CL} = -\frac{R_f}{R_i}$

   (A_{CL} is not depending on A_{OL})

2. If $R_f = R_i$, $A_{CL} = -1$

   ∴ Inverting amplifier can be designed for unit gain.

   (But 180° phase inversion will be there).

3. If R_f is a multiple of R_i

   e.g. If $R_f = 5\,R_i$

   Then $A_{CL} = -5$

   here circuit gives a voltage gain of 5 along with 180° phase inversion.

4. Inverting amplifier gives constant voltage gain.

Input and output impedance of an inverting Amplifier

We know, the *input impedance* of Op-Amp is high. But this is not true for an inverting amplifier.

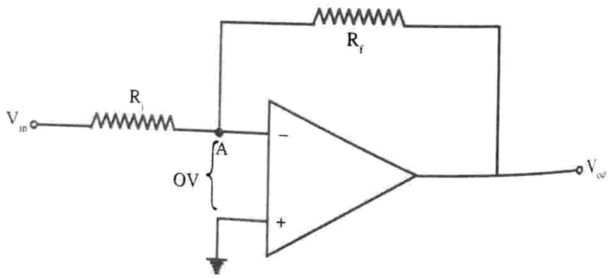


Fig. 5.12

Here the voltage source 'sees' an input resistance (R_i) that is going to virtual ground.

∴ $Z_i = R_i$

R_i is very very small (∵ $I_i = I_f$)

∴ Z_i is less

But the output impedance of the inverting amplifier is the parallel combination of R_f and output impedance of op-amp.

Negative feedback reduces output impedance of the inverting amplifier less than that of the output impedance of op-amp.

Problems

14. *In an inverting Op-Amp the input resistance $R_i = 2K\Omega$ and feedback resistor (R_f) is $10K\Omega$. The input signal is 500 mV. Calculate the voltage gain of the amplifier and output voltage. Also find the input impedance of the amplifier.*

Ans: Voltage gain of amplifier

$$A_{CL} = -\frac{R_f}{R_i} = -\frac{10K\Omega}{2K\Omega} = -5$$

$$= \mathbf{5}$$

(–ve sign represents phase change of 180°)

Output voltage of the amplifier

$$V_0 = A_{CL}\,V_i$$

$$= -5 \times 500 \times 10^{-3} = -2500 \times 10^{-3}$$

$$= \mathbf{-2.5}\ \mathrm{V}$$

Input impedance $Z_i = R_i = 2K\Omega$

Slew rate

15. *What is slew rate ? On what factors does it depend ?*

(CU Nov. 2015)

It is a measure of how fast the output voltage can change in response to changes in the input frequency. (unit V/μs)

Slew rate is dependent up on the high frequency response of the amplifier stages within Op-Amp.

Slew rate of an Op-Amp is fixed.

Slew rate = $2\pi f V_m$ v/s

16. Using Fig.6.36 find closed loop voltage gain and input impedance.

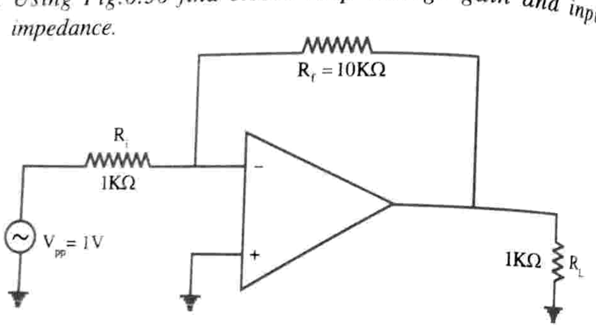


Fig. 5.13

Ans: $A_{CL} = -\frac{R_f}{R_i} = \frac{-10K\Omega}{1K\Omega} = -10$

$Z_i = R_i = 1K\Omega$

$A_{CL} = \frac{V_{out}}{V_{in}}$

$V_{out} = V_{in} \times A_{CL} = V_P \times 10 = 10\ V_P$ $(\because V_{in} = V_P)$

$\therefore$ Peak output voltage = $10 \times \frac{V_{PP}}{2}$

$V_{out} = 10 \times \frac{1}{2} = 5V$

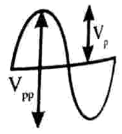


Fig. 5.14

Non-Inverting amplifier

Here input signal is applied to the non-inverting (+ve) terminal. The feedback of output voltage is done through feedback resistor R_f. R_i is the input resistance.

R_f and R_i together form a voltage divider at the –ve inverting input. This produces a –ve feedback in the circuit. [When V_{out} increases, the voltage at the inverting input (–ve) also increases. The difference between voltage at the two (+ve and –ve) terminals is amplified. So when the output voltage increases, differential voltage at input decreases. i.e., a –ve feedback occur at the input].

The output signal is in phase with input signal. i.e., non-inverted.

Problem

17. Derive an expression for voltage gain of a non-inverting amplifier.

Ans: Same current flows through the input resistance R_i and feedback resistor R_f. So no current flows through the op-amp.

$\therefore$ Input current = Output current

$$I_i = I_o$$

$$\frac{V_A - V_i}{R_i} = \frac{V_i - V_o}{R_f}$$

$$V_A = 0$$

$$\therefore -\frac{V_i}{R_i} = \frac{V_i - V_o}{R_f}$$

$$\frac{V_o - V_i}{V_i} = \frac{R_f}{R_i}$$

$$\frac{V_o}{V_i} - 1 = \frac{R_f}{R_i}$$

$$\frac{V_o}{V_i} = 1+\frac{R_f}{R_i}$$

$\therefore$ Voltage gain $\boxed{A_{CL} = 1+\frac{R_f}{R_i}}$

Note: For Non-inverting amplifier

1. $A_{CL} = 1+\frac{R_f}{R_i}$

   It means that this voltage gain is always greater than that of inverting amplifier by a value of 1. e.g., If 120 is the gain of an inverting amplifier, then 121 = 120 + 1 will be the gain of noninverting amplifier.
2. Voltage gain is +ve. (This is because the output is in phase with input)

18. Distinguish between Inverting and Non-inverting amplifiers using figures. *(CU Nov. 2015)*

19. Find the output voltage for an input of 6 V_{rms} in the fig. 6.39.

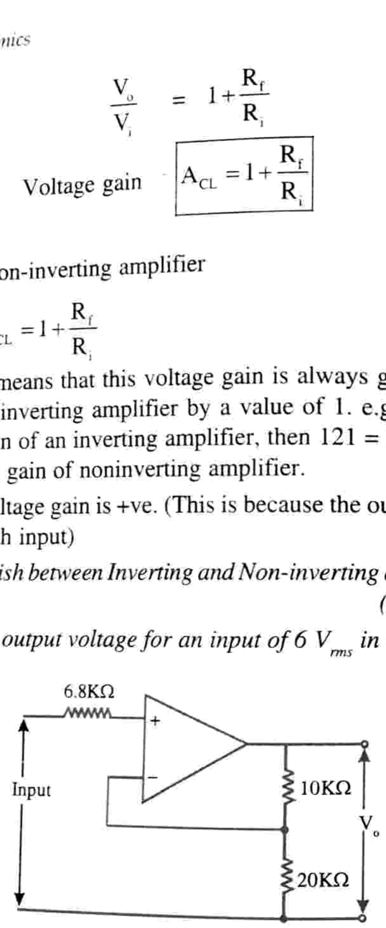


Fig. 5.15

Ans: Input is given to +ve terminal. So it is a non-inverting type.

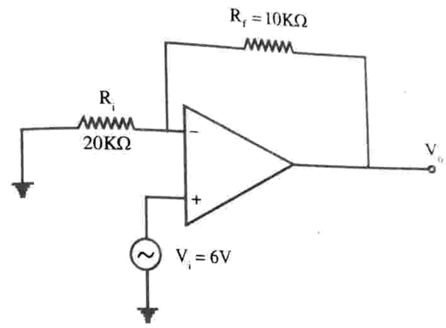


Fig. 5.16

$$\frac{V_o}{V_i} = 1+\frac{R_f}{R_i}$$

$$\frac{V_o}{6} = 1+\frac{10}{20}$$

$$= 1+\frac{1}{2} = 1.5$$

$$V_o = 6\times 1.5 = \mathbf{9V}$$

$V_{in} = 6V$
$V_o = ?$
$R_f = 10K\Omega$
$R_i = 20K\Omega$

20. Draw the circuit diagram and derive the expression for voltage gain of an inverting and non inverting configuration using op-amp. *(CU Nov. 2018)*

Hints: Circuit diagram of an inverting amplifier – Derivation for the expression for voltage gain – Circuit diagram of non inverting amplifier – Derivation for the expression for voltage gain.

Applications of Op-Amplifier

Op-Amp used as integrator, differentiator, summing amplifier, difference amplifier, unity gain buffer, scale/sign changer etc.

Summing Amplifier (Adder)

An amplifier whose output voltage is the sum of the input voltages. It is an inverted Op-Amp. It can accept two or more inputs.

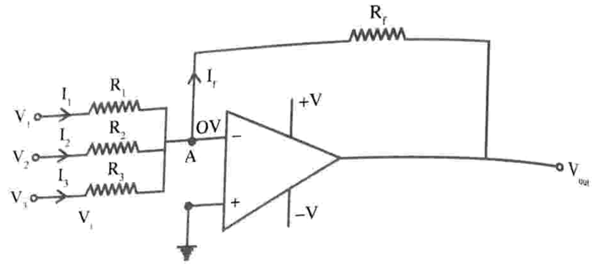


Fig. 5.17

V_1, V_2, V_3 ... are input voltages. I_1, I_2, I_3 ... are input currents. A is the virtual ground (at OV).

$\therefore$ There is no current to the input (inverting or –ve) terminal.

at A, $I = I_1 + I_2 + I_3 = I_f$

$$V_{out} = -I_f R_f$$

$$= -R_f(I_1 + I_2 + I_3)$$

$$= -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

If $R_1 = R_2 = R_3 = R$

$$V_{out} = -\frac{R_f}{R}(V_1 + V_2 + V_3)$$

i.e., the output voltage of a summing amplifier is proportional to the negative of the algebraic sum of its input voltages.

Case (i) If gain $-\frac{R_f}{R} = 1$ (unity gain)

$$V_{out} = -(V_1 + V_2 + V_3)$$

i.e., when the gain of the summing amplifier is unity, the output voltage will be the algebraic sum of the input voltages.

Case (ii) If gain > 1

i.e. $R_f > R$

$$V_{out} = -\frac{R_f}{R}(V_1 + V_2 + V_3)$$

Problems

21. *For the circuit shown, determine the output voltage.*

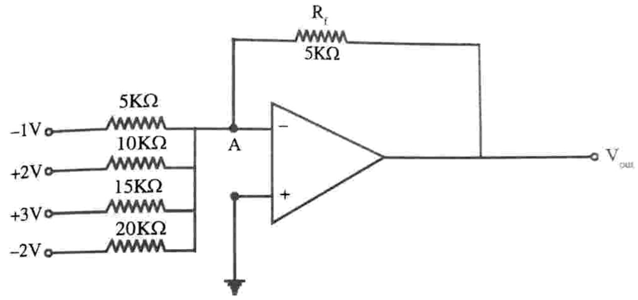


Fig. 5.18

$$V_{out} = -R_f\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4}\right]$$

$$= -5\left[\frac{-1}{5} + \frac{2}{10} + \frac{3}{15} + \frac{-2}{20}\right]$$

$$= -\left[-1 + 1 + 1 - \frac{1}{2}\right]$$

$$= -0.5 \text{ V}$$

22. *What is an op-amp? Draw the circuit diagram and explain the working of op-amp as a summing amplifier.* *(CU Nov. 2020)*

23. *Obtain the output of an Op-Amp adder with the following data. Inputs are* $V_1 = 0.1V, V_2 = 0.3V, V_3 = 0.5V$. *Input resistors are* $R_1 = 2K\Omega,\ R_2 = 3\Omega$ *and* $R_3 = 4K\Omega$ *and the feedback resistor* $R = 12\Omega$ *(CU Nov. 2016)*

Ans:
$$V_{out} = -R_f\left[\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}\right]$$
$$=-12\left[\frac{0.1}{2}+\frac{0.3}{3}+\frac{0.5}{3}\right]$$
$$=12\left[\frac{0.3+0.6+1}{6}\right]=2\times1.9=\mathbf{3.8}\text{V}$$

24.

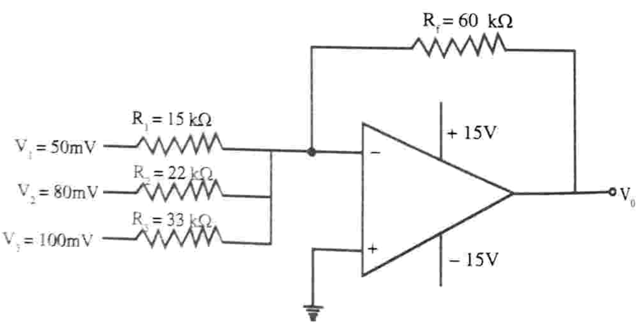


Fig. 5.19

Find the a.c. output voltage and find the value of the compensating resistance which is required to add to non-inverting input?

Ans: For inverting,

closed loop gain

$$A_{CL_1} = \frac{R_f}{R_1} = \frac{60}{15} = 4,\quad A_{CL_2} = \frac{R_f}{R_2} = \frac{60}{22} = 2.73$$
$$A_{CL_3} = \frac{R_f}{R_3} = \frac{60}{33} = 1.82$$

a.c. output voltage

$$V_0 = A_{CL_1}V_1 + A_{CL2}V_2 + A_{CL3}V_3$$
$$= 4\times50 + 2.73\times80 + 1.82\times100$$
$$= 200+218.4+182$$
$$= 600.4\text{mV}$$

If the summing circuit needs to be compensated by adding an equal resistance to the non-inverting input, the resistance is

$$= 15k\Omega // 22k\Omega // 33k\Omega$$
$$= 7.02k\Omega$$

2. Integrator

The circuit whose output voltage is integral of the input voltage.

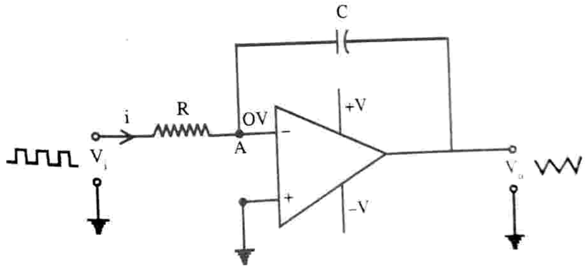


Fig. 5.20

This circuit performs the mathematical integration of the input signal.

Table 5.1

Input signal	Integrator output
Sine	Minus cosine
Step function	Ramp functiion
Square wave	Triangular wave
Ramp function	Parabola
Triangular wave	Modified Parabola
Sawtooth wave	Parabolic wave

Note: The output of an integrator is proportional to the area of the input wave form over a period of time.

Theory

Charge on Capacitor C

$$Q = CV = C(V_A - V_o)$$

$$V_A = 0$$

$$\therefore \quad Q = -CV_o \qquad \dots (1)$$

But $$Q = \int_0^t i\,dt$$

Substituting in (1)

$$\int_0^t i\,dt = -C\,V_o \qquad \dots (2)$$

By ohm's law

$$i = \frac{V_i - V_A}{R} = \frac{V_i}{R} \qquad \because V_A = 0 \qquad \dots (3)$$

Substituting (3) in (2)

$$\int_0^t \frac{V_i}{R}dt = -C\,V_o$$

$$V_o = -\frac{1}{RC}\int_0^t V_i\,dt$$

$$V_o \propto \int_0^t V_i\,dt$$

i.e. the output voltage is proportional to the integral of the input voltage.

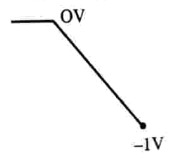
Note: (i) Here RC is called time constant τ. For proper integration, the time constant RC should be much greater than the width of input pulse (at least 10 times)

$\therefore \quad RC > 10T$

(ii) When $V_i = 0$, the integrator works as an open-loop amplifier.

Applications of Op-Amp integrator

i) To produce a ramp output voltage (Ramp voltage is linearly increasing or decreasing voltage)



Problem

25. *If $V_i = 1V$, $R = 1M\Omega$, $C = 1\mu F$ find output voltage of Op-Amp integrator.*

Ans: $$V_{out} = -\frac{1}{RC}\int_0^t V_i\,dt$$

$$= -\frac{1}{1\times10^6\times1\times10^{-6}}\int_0^t 1\times dt$$

$$= \int_0^t dt$$

Here the output voltage grows over a period of time. It provides a ramp voltage.

Draw the circuit diagram of an op-amp Integrator and explain its working. (CU 2017 Nov.)

3. Differentiator

The circuit whose output voltage is proportional to the differential coefficient of change of the input voltage.

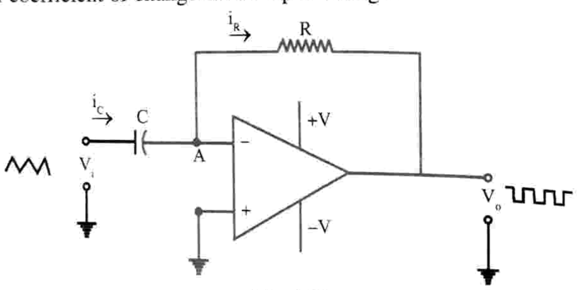


Fig. 5.21

This circuit performs the mathematical differentiation of the input signal

A is the virtual ground. Due to virtual ground

$$i_R = \frac{0 - V_o}{R} = -\frac{V_o}{R}$$

$$V_C = V_i - 0 = V_i$$

$$i_C = C\cdot\frac{dV_C}{dt} = C\cdot\frac{dV_i}{dt}$$

equating

$$-\frac{V_o}{R} = C\cdot\frac{dV_i}{dt}$$

$$V_o = -RC\frac{dV_i}{dt}$$

i.e., output of differentiator is proportional to the rate of change of its input signal.

If V_i is constant, $\frac{dV_i}{dt} = 0$

$\therefore$ $V_o = 0$

$\therefore$ Faster the input voltage changes, larger will be the output voltage.

Table 5.2

Input signal	Differentiator output
Sine	Cosine
Step function	Single pulse
Square wave	Pulse train
Ramp function	Step function
Triangular wave	Square wave
Sawtooth wave	Step function

Problems

26. *Draw the circuit diagram and explain the working of differentiator using op-amp* *(CU Nov. 2018)*

Hints : Circuit diagram – explanation.

27. *For a differential circuit, the input is a sinusoidal voltage of peak value 10mV and frequency 1 KHz. R = 100KΩ and C = 0.1μF. Find output.*

Ans: $V_m = 10mV$

$$V_i = V_m \sin\omega t = V_m \sin 2\pi f t$$
$$= 10\sin 2\times\pi\times 1000t$$
$$= 10\sin 2000\pi t \ \ mV$$

$$V_o = RC\frac{dV_i}{dt} = RC\cdot\frac{d}{dt}(10\sin 2000\pi t)$$
$$= 100\times 10^3\times 0.1\times 10^{-6}(2000\pi)(10)\cos 2000\pi t$$
$$= \mathbf{200\pi\cos 2000\pi t} \ \ mV$$

28. *Consider a square wave input of a differentiator circuit. If the input goes from 0V to 10V in 0.2 ms, determine the output voltage. $R = 1K\Omega$ and $C = 0.1\mu F$.*

Ans:

$$V_o = -RC\frac{dV_i}{dt}$$

$$= -1\times10^3\times0.1\times10^{-6}\cdot\frac{(10-0)}{0.2\times10^{-3}}$$

$$= \frac{10^{-4}\times10}{0.2\times10^{-3}} = \frac{100}{0.2} = 5V$$

29. *A 5 mV, 2 KHz sinusoidal signal is given to the input of an op-amp integrator. Given $R = 10K\Omega$ and $C = 0.1\mu F$. Determine its output voltage.*

Ans:

$$V_{rms} = 5mV, \quad f = 2KHz$$

$$R = 10K, \quad C = 0.1\mu F.$$

$$V_i = V_m \sin\omega t$$

$$V_i = V_m \sin\omega t = V_m \sin 2\pi ft$$

$$= 5\sqrt{2}\sin 2\pi\times2\times10^3 t \text{ mV}$$

$$V_o = -\frac{1}{RC}\int_0^t V_i\, dt$$

$$= \frac{-1}{10\times10^3\times0.1\times10^{-6}}\int(5\sqrt{2}\sin 4000\pi t)dt$$

$$= \frac{-5\sqrt{2}}{10^{-3}}\int(\sin 4000\pi t)dt$$

$$= -5\times10^3\sqrt{2}\left[\frac{-\cos(4000\pi t)}{4000\pi}\right]$$

$$= \frac{5\sqrt{2}}{4\pi}\cos 4000\pi t \text{ mV}$$

Exercise

1. The closed loop gain of an op-amp is not depending on its characteristics – Explain.

   Ans: The closed loop gain of a Op-Amp with –ve feedback is independent of its characteristics. It depends on the feedback ratio.

   $$A_f = \frac{1}{\beta}$$

2. 'For an op-amp we do not express its lower cut-off frequency. We only express upper cut-off frequency'. Explain.

   Ans: Op-amp is a direct coupled amplifier. It has no lower cut off frequency. As frequency increases, the gain decreases. At 0.707 of its maximum value, upper cut off frequency exists. Band width is upper cut off frequency –0)

3. 'An op amp can also be used as a current amplifier. Explain.

4. Explain the effect of applying negative feedback in non-inverting Op-Amp?

   Ans: When –ve feedback is used, its A_{CL} depends only on the values of external resistances. Z_i increases. Z_o decreases. Upper cut off frequency also increases.

5. Explain 'unity gain frequency' in an Op-Amp.

   Ans: It is that frequency where gain reduces to unity. (It gives B.W. of op-amp).

6. Explain with a diagram, how two supply voltages +V and –V are obtained from a single dual power supply?

7. Why the gain of an amplifier circuit is not depending on the gain of the op-amp used?

8. What is CMRR? Explain the importance of large value of CMRR. (CU Nov. 2017)

Ans: The ratio of differential mode gain to the common mode gain.

Larger the CMRR, better is the differential amplifier to eliminate common mode signals.

Common Mode Rejection Ratio (CMRR)

Explanation

Different forms of interference, static, induced voltages, noise etc., drive a differential amplifier in the common mode. These unwanted signals should not be present at the output. The differential amplifier has the property of rejecting such common mode signals. Therefore, CMRR is the ability of a differential amplifier to reject a common mode signal such as noise.

Define CMRR

CMRR is defined as the ratio of the differential mode gain to the common - mode gain.

$$\text{CMRR} = \frac{\text{Differential voltage gain}}{\text{Common} - \text{mode voltage gain}} = \frac{A_d}{A_C}$$

In ideal case, $A_C = 0$ and $A_d = A_v$ is very large. Therefore CMRR is very large.

Problems

30. *If V_{in} in common mode is 1V, voltage gain $A_V = 100$ and V_{out} in common mode = 0.01V, calculate CMRR.*

Ans: $$\text{CMRR} = A_V \times \frac{V_{in(CM)}}{V_{out(CM)}}$$

$$= \frac{100 \times 1}{0.01} = 10000$$

i.e., if a signal of $V_{in(CM)} = 1V$ is present at the input, then the output voltage is attenuated by a factor of CMRR = 10000. Hence a large value of CMRR is desirable.

The CMRR (expressed in dB) defines how good the amplifier is at attenuating common mode input voltages.

CMRR in decibels (dB) is denoted by ρ

$$\rho = 20 \log_{10} \text{CMRR}$$

$$= 20 \log_{10} \frac{A_d}{A_C}$$

Note : At low frequencies CMRR is about 100dB which is to be converted to an ordinary number 100,000.

31. *If $A_{DM} = 3500$ and $A_{CM} = 0.35$, the CMRR of an Op-amp is* *(CU Nov. 2018)*

Ans: $$\frac{A_d}{A_C} = \frac{A_{DM}}{A_{CM}} = \frac{3500}{0.35} = 10000$$

32. *A certain differential amplifier has a differential voltage gain of 2000 and a common mode gain of 0.2. Determine CMRR and express it in dB* *(KU May 2017)*

Ans: $$\text{CMRR} = 20\log_{10}\frac{A_d}{A_C}$$

$$= 20\log_{10}\frac{2000}{0.2}$$

$$= 20\log_{10} 10000$$

$$= 20 \times 4.0000 = \mathbf{80dB}$$

9. Explain virtual ground

For an ideal op-amp $R_{in} = \infty$,

$\therefore$ i_2 is zero. Open loop gain $A_{OL} = \infty$

$\therefore$ V_2 is zero. Since $i_2 = 0$, $v_2 = 0$, current through R_2 = current through R_1.

Since $v_2 = 0$, the inverting input (G) acts like a ground.

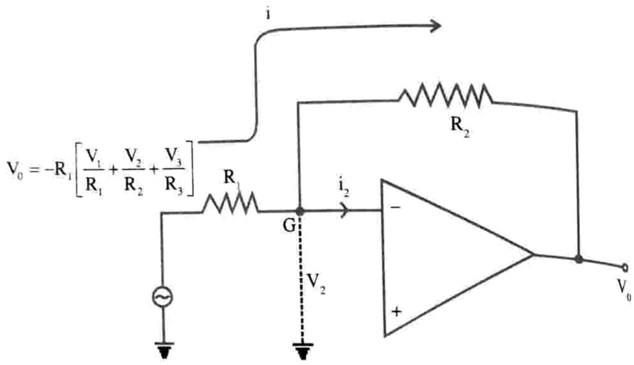


Fig. 5.22

10. 'The gain of a buffer amplifier is unity'. Explain.

11. What is the difference between open-loop and closed loop gains of an op-amp?

12. State True or False

   a) The internal gain of the Op-Amp is more than its closed loop gain.

   b) Negaitve feedback decreases the output impedance of non-inverting op-amp.

   c) The gain Band-width product of an op-amp is not constant.

   d) In a linear op-amp the signals are always sine waves.

Assignments

1. The CMRR of a differential amplifier is 55dB. If its gain in differential mode (A_d) is 1200, find its gain in common mode (A_C).

   Hints : $\text{CMRR} = \dfrac{A_d}{A_C}$

$$\text{CMRR (dB)} = 20\log_{10}\frac{A_d}{A_C}$$

$$A_C = 2.13.$$

2. In an inverting op-amp the input resistor $R_i = 3.3k\Omega$. $R_f = 10k\Omega$. Input signal is 200mV. Find the voltage gain of the amplifier and output voltage. Also calculate the input impedance of the amplifier.

   Hints: $A_f = -\dfrac{R_f}{R_i} = \dfrac{10}{3.3} = -3.03$

   $v_0 = A_f v_i$

   $= -3.03 \times 200 \times 10^{-3}$

   $= 0.6V$

   Input impedance = R_i = $\underline{\underline{3.3k\Omega}}$

3. In an op-amp used as a summing amplifier the input voltages are $-3V$, $-2V$ and $+4V$. If the input resistor is $4k\Omega$ and $R_f = 6k\Omega$, find the output voltage.

   Hints: $R_1 = R_2 = R_3 = 4k\Omega$

   $R_f = 6k\Omega$

   $$v_0 = -R_f\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right]$$

   $$= -6\left[\frac{-3}{4} + \frac{-2}{4} + \frac{4}{4}\right]$$

   $$= -6\left[\frac{1}{4}\right] = \frac{-6}{4} = \underline{\underline{-1.5V}}$$

4. In an op-amp used as differentiator, $R_i = 1M\Omega$ and $C = 2\mu F$. If a signal $v_i = [3\sin 1000\pi t]mV$ is used as input voltage, calculate output voltage.

Hints: $v_0 = RC\frac{dV_i}{dt}$

5. Mention any three characteristics of op-amp.
6. Explain the principle of working of op-amp. How is it different from ordinary transistor amplifier?
7. If $V_i = 0.4V$, $R = 10^6\Omega$, $C = 0.5\mu F$, calculate output voltage if the op-amp is used as an integrator.
8. 'The closed loop gain of an op-amp is not depending on its characteristics'. Is this correct?

   Ans: Yes. It depends only on β, the feedback ratio.
9. Can you use an op-amp as current amplifier?

   Ans: Yes.
10. The gain of an inverting op-Amp is ....

    Ans: equal or less than or greater than 1
11. In a linear op-amp, signals are always .... waves

    Ans: sine.
12.

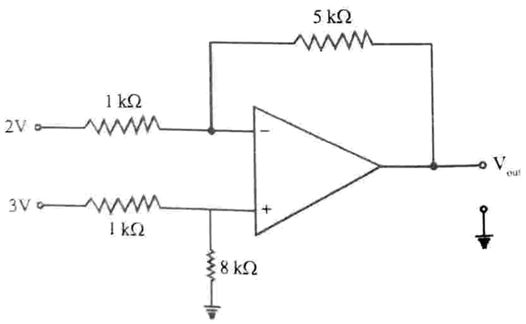


Fig. 5.23

Fig. represents in ideal op amp. Find its output voltage.

Ans : 6V

13.

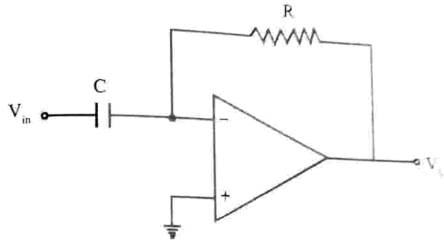


Fig. 5.24

Fig. represents an ideal op-amp. If V_{in} is a triangular wave, what will be the nature of V_0.

Ans: Square wave.